16B.3

IMPROVED THUNDERSTORM DETECTION, TRACKING AND ASSESSMENT PRODUCTS FOR ENVIRONMENT CANADA RADARS

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1. INTRODUCTION

The Meteorological Service of Canada (MSC) uses 31 C-band Doppler radars (Lapczak et al, 1999) to aid its weather forecast and warning production. These forecast and warning products are produced by two aviation forecasts centres and five regional storm prediction centres. That means that each office monitors many radars at once, including cross border U.S. National Weather Service (NWS) radars. A severe weather meteorologist on the Canadian Prairies, for example, monitors nine doppler radars in their region plus three adjacent Canadian radars and four NWS radars. In addition, the forecaster's area of responsibility extends well beyond the coverage of the radar. Forecasters must monitor vast areas yet still may be required to hone in on individual thunderstorms. Therefore, the requirements for sophisticated radar software are demanding.

The Canadian forecaster's primary analysis and display tool for radar data is the Unified Radar Processing (URP) software. URP produces basic conventional and velocity-based products. Each radar uses a 5-minute 24 elevation conventional scan strategy producing detailed volumetric data. This is followed by a 5-minute four elevation doppler scan.

A more sophisticated suite of products is produced by an MSC-designed system known internationally as CARDS (Canadian Radar Decision Support system). These products are designed detect and track thunderstorm cells, and to help assess their severity (Joe, et al, 2002).

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A collaborative project between the Hydrometeorological and Arctic Lab and the Prairie and Arctic Storm Prediction Centre has been developing and assessing improvements to CARDS and URP. Some of the improvements have been cosmetic (color tables, units, etc.), some have addressed errors in the original software, while many others have been significant, including the integration of numerical weather prediction (NWP) and lightning data.

2. CARDS PRODUCTS

Radar processing has traditionally been done in isolation from other weather data. However, forecasters integrate all datasets when developing a diagnosis. CARDS was designed to access other data sources such as model data and lightning, though only basic lightning information has ever been utilized.

The primary focus for CARDS has been severe thunderstorms, while basic doppler and conventional data is used for other weather problems. The fundamental requirement for severe thunderstorm tracking and diagnosis is to have an accurate detection of a thunderstorm "cell". The 24-tilt scan strategy utilized by the MSC radars provides highly detailed volumetric data which allows for sophisticated storm cell detection and tracking.

2.1 Cell Identification

CARDS identifies and tracks thunderstorm cells using the TITAN (Thunderstorm Identification, Tracking, Analysis and Nowcasting) technique (Dixon and Wiener, 1993). The Maximum Reflectivity (MaxR) field from the volume scan is projected onto a horizontal plane. An echo is identified as a cell if its MaxR field meets a reflectivity threshold over a sufficiently large area. The thresholds are configurable and are currently set to 45 dBZ over at least 4 radar bins (> ~4km^2). According to the TITAN technique, CARDS calculates a best-fit ellipse for the shape of the cell.

This approach tends to get overly sensitive close to the radar since radar bins are very small and only a 2x2 bin area is required. The approach can also falsely detect non-meteorological targets (AP) that often results in the system tracking mountains, among others. To better filter potential thunderstorms, a new configuration has been developed to include a more sophisticated reflectivity threshold approach and to incorporate model temperature data. The potential storm's core is a coherent three-dimensional "blob" whose volume exceeds a minimum threshold:

- Core dBZ threshold = 45 dBZ
- Core minimum volume = 50 km^3
- Cold minimum volume = 5 km^3
- Cold temperature threshold = -10C
- Minimum allowed feature top = 2.0 km

The temperature profile for each potential cell is interpolated from the Canadian regional operational model: Global Environmental Multi-scale or GEM (Côté et al, 1998, and Yeh et al, 2002). To ensure that the cell candidate first meets the continental cold rain process requirement, the detected core must have at least 5 km^3 of its volume below -10 C. At this stage, lightning data from the Canadian Lightning Detection Network (CLDN) is not used since the system often fails to detect in-cloud and weak cloud to ground strikes, especially in the early stages of the thunderstorm's evolution.

For each cell meeting the thunderstorm cell requirement, the horizontal footprint of the cell's core is calculated. Within a configurable distance from this footprint, 26 cell attributes are calculated, including BWER, maximum hail size, echo top, cell core volume, etc. This is an improvement over the existing CARDS approach which simply looked within 20 km of the storm's centroid. The new approach takes better into account the cell's true shape.

Lightning data from the CLDN is included at this point. The use of lightning data for assessing thunderstorm severity is being examined by MSC (McDonald et al, 2006). The inclusion of this data allows for real-time assessment of cell-based lightning data. The lightning data is correlated with each cell where the time window is centered ± 5 minutes of the radar time stamp. This cell-based information includes:

- Total lightning
- Percentage of positive cloud to ground flashes
- Maximum amperage
- Flash density, and
- FlashTendency (change in number of flashes/min) over last 10 minutes.

2.2 Multi-radar Cell Merge for Composite

The integration of data from multiple radars introduces a number of problems due to overlapping data. Cells in these overlapping areas are seen from different angles and the data may appear different for each radar. C-band radars are also notorious for attenuation. Sometimes a nearby radar cannot detect the cell well, while another radar farther away sees it clearly. Another problem is that radars can vary somewhat in their sensitivity. Over time, some radars may become a bit "hot" (too sensitive) and others may become too "cool". In this situation, a storm equi-distant between two radars may be seen as more intense by one radar than by the other.

CARDS uses the maximum reflectivity (MaxR) to decide which radar "owns" the cell. When the forecaster displays the cell information, the only information provided is from this assigned radar. Given the problems above, the view displayed may not be the most appropriate to the forecaster, yet the forecaster is stuck with it. This can be particularly frustrating since the MSC radars only display detailed velocity data out to 112 km. This could mean that no storm-based velocity data could be made available to the forecasters if the system chooses a more distant radar.

The new method being tested keys on the bottom height of the cell core. Whichever radar sees the lowest part of the cell core (usually the nearest the radar) is the "owner", and this radar will be able to provide the view of the cell. However there may be significant attenuation, or the cell may be in the radar's "cone of silence".

2.3 Cell tracking

Cell tracking is based on the Thunderstorm Identification, Tracking, Analysis, and Nowcasting (TITAN) scheme (Dixon and Wiener, 1993). Using observed cell velocity, the cells at the previous radar time step T-1 are projected forward to the current time T, and compared against the current observed unmatched cells. CARDS calculates the observed cell velocity as the latest 10 minute motion. The new approach is to calculate and use 30 minute (configurable) mean cell velocity when tracking. If the cell is less than 30 minutes old, the system uses the lifespan of cell. Knowledge of mean velocity provides more consistent tracking and provides more reliable input into Warnings. For a new cell, instead of giving it no velocity, it is projected forward using the GEM's 0-8 km mean wind vector calculated for the cell's location.

The Hungarian algorithm (Kuhn, 1955 and Munkres, 1957) is used to find the best match between all forecast cells and observed cells, allowing for generation of new cells and dissipation of old cells. If a "cost" is assigned between all possible forecast and observed matches, the Hungarian algorithm will find the set of matches that minimizes the overall "cost". CARDS assigns a cost by looking at the distance error between a forecast and observed cell. The new method enhances this by using the distance error as well as the cell core volume ratio between forecast and observed cell. Given an equal number of forecast and observed cells, the Hungarian method will match them all, regardless of the meteorological suitability. The new method disallows unreasonable matches that deviate "too much" from their neighbors or from the mean flow. The rules still need fine-tuning in squall line situations where a "cell" centroid may move erratically due to the addition or shedding of individual cells.

2.4 SUDDS Composite Display

Once CARDS detects thunderstorm cells, calculates attributes, merges multiple radar cells into a single composite, and tracks them, the information is made available to the forecaster via the SUmmer Drill Down Scenario (SUDDS) display. For Canadian forecasters, this system displays the radar composite view from every radar in and near their area of responsibility, as well as detailed cell information for each tracked cell. A Storm Cell Identification Table (SCIT) is also displayed, listing the rank and attributes for each cell being tracked. The forecaster simply clicks on any identified cell displayed in the composite SUDDS view or on the SCIT, and a new Cell View window is generated. This window displays a cell-based view of the storm at varying altitudes, using both doppler and conventional data, and also displays various other fields such as BWER (Bounded Weak Echo Region), hail size, mesocyclones and spectrum width.

2.5 BWER

The existence of the Bounded Weak Echo Regions (BWER) is an important feature within supercell thunderstorms as evidence of a strong updraft with rotation. Finding a BWER is somewhat like finding an "upside down cup" pattern in the reflectivity volume scan. CARDS tries to find the storm's BWER by examining each radar bin and searching outward and upward in the bin's vicinity for gradients in excess of 8 dBZ per radar bin. However, the algorithm did not look in enough directions, did not require a vertical bound, nor did it give partial credit for gradients less than 8 dBZ/bin. The result was that the algorithm was not always effective.

The algorithm has been enhanced to look within 10 km of each radar bin, in 8 horizontal directions, 8 upward-diagonal directions and 1 vertical direction (17 in total), searching for gradients of at least 8 dBZ per bin, but giving partial credit to gradients of 6 dBZ or greater. A vertical bounding gradient of at least 6 dBZ per bin is required. BWER volume as well as BWER maximum height are calculated. The new BWER algorithm runs about 10 times faster than the old algorithm. The BWER information is displayed in the conventional data Cell View window (figure 1) and in the SCIT (figure 2).

2.6 Maximum Hail Size

The hail size algorithm empirically relates hail size with the freezing level, VIL and height of 50 dBZ level, based on a study done at sea level in Sydney, Australia (Treloar, 1998). CARDS uses the GEM model freezing level above sea level at the radar site. However, across Canada, some radars are located well above sea level, and the algorithm's performance has been inconsistent.

The algorithm has been modified to use the GEM model freezing level interpolated to the thunderstorm cell, and expressed in terms of the height above ground from radar ground level. While this approach appears to be more appropriate meteorologically, preliminary calculations suggest that is will predict generally larger hail sizes, especially over the rising terrain of the Western Prairies. Data is also displayed conventional data Cell View window and in the SCIT.

Preliminary results from testing during the summer of 2008 indeed indicated the over-prediction of hail size, though the performance was more consistent. The data collected may provide the impetus for development of a Canadian hail algorithm.

2.7 Rank Weight

As mentioned earlier, one of the cell-based displays for forecaster is the SCIT (figure 2). This provides a tabular assessment and intensity ranking (Cell Rank Weight) of each tracked thunderstorm.

The CARDS Cell Rank Weight score gave equal weighting to 7 parameters:

- Average BWER Height
- Average Mesocyclone Strength,
- Average Hail Size
- Average Vil Density
- Average Reflectivity Z,
- Average Echo Top of the 45 dBZ
- Average WDRAFT (Stewart, 1991)

By using the average values of each parameter, the maximum values are masked out. Routinely, the more severe storms, with intense small-scale elements, were under-ranked.

The new algorithm utilizes the maximum value for these parameters except for the mesocyclone strength, as it can be noisy and occasionally too large near the radar. In addition, the volume of the BWER was added to the Rank Weight.

Of the eight parameters, forecasters generally felt that Maximum Hail Size correlated better with severe weather occurrences than any other parameter. This was likely due to the limited range performance of algorithms like Mesocyclone Strength and BWER Height. For the new Rank Weight, Maximum Hail Size was weighted 30% of the overall rank while the remaining seven parameters were equally weighted at 10% each. Preliminary results suggest that this approach improved the overall performance of Cell Rank Weight.

2.8 Velocity Azimuth Display (VAD)

The original CARDS VAD (figure 3) provided basic doppler-based vertical velocity information. The display was somewhat difficult to interpret by forecasters as the information was in the less-used units of m/s and was presented in a non-traditional format.

The new VAD (figure 4) adds two traditional displays: 1) hodograph display and 2) wind barb vs. height display. All three displays present the data for 0.5°, 1.5°, 3.5° elevation angles. In addition, if data is available to sufficient depth, the 0-1 km and 0-3 km storm-relative helicities are calculated utilizing the observed mean storm velocity of all the radar's cells, and the GEM-derived Bunkers (Bunkers et al, 2000) storm velocity. If radar velocity data is present to sufficient depth, the 0-6 km Bulk Shear is calculated.

2.9 Vertical Cross-Section

CARDS provides the capacity to generate vertical cross-sections anywhere within a radar's domain. The new vertical cross-section (figure 5) now allows for the overlay of GEM-derived temperature and moisture data. This approach allows forecasters to more readily assess bright bands, as well as hail and snow production potential.

Radial velocity vertical cross-sections now show the corresponding reflectivity cross-section (figure 6).

2.10 Storm-relative velocities

CARDS only displays ground-relative radial velocity information. Mesocyclone couplets should be more evident in storm-relative velocity mode. The new prototype incorporates storm-relative velocities by subtracting off storm motion vector from radial velocities. The storm motion vector can be input from one of three methods:

1) GEM-derived Bunkers storm velocity
2) Observed cell(s) storm velocity shown in Doppler Cell View & VAD
3) User-defined storm velocity for each radar via a desktop interface

2.11 Constant Temperature PPI (CoTPPI)

Precipitation occurring at certain temperatures aloft can provide valuable insight into the forecaster's diagnosis, including bright bands, freezing rain, hail growth potential, snowfall potential, etc. The CoTPPI (figure 7) displays PPIs of radar data on any GEM-based temperature surface, including dry-bulb, dew-point and wet-bulb.

2.12 Melting Level overlay

CARDS displays both CAPPI and PPI reflectivity products. Either of these products could intercept a bright band melting level aloft. This often results in the over-estimation of precipitation intensity due to the enhanced reflectivity of wet snow. A new user-accessible overlay is available that will superimpose a GEM-derived wet-bulb temperature melting level over the radar data.

2.13 5-Minute Base Reflectivity Loops

Even though Canadian radars are on a 10-minute scan cycle, the base elevation 0.3 degree sweep from the conventional volume scan and 0.3 degree long range sweep from the doppler scan are roughly 5 minutes apart. Loops of 5-minute base reflectivity are now being produced using the long range doppler scan and the lowest elevation conventional scan with ground clutter filtering.

3. ONGOING WORK

The new CARDS products were made available for testing in real-time during the summer of 2008. Forecasters at the Prairie and Arctic Storm Prediction Centre (PASPC) accessed this data in addition to the traditional CARDS products already available to them.

PASPC severe weather meteorologists evaluated the new system and provided ongoing feedback throughout this summer. All radar data was archived and more rigorous assessment is planned before summer of the 2009. Successful products will eventually be incorporated into the national CARDS used by all MSC Storm Prediction Centres.

A prototype three-dimensional storm viewer has also been developed and is under assessment. Work on the integration of lightning data and radar for severe weather detection and prediction continues.

4. SUMMARY

CARDS is an advanced radar displays system that aids Canadian forecasters in assessing severe thunderstorms and other severe weather. While the system has been successfully incorporated into MSC forecast offices, some aspects were deficient. In addition, the potential of CARDS has yet to be fully achieved. A co-operative project, led by MSC's Hydrometeorological and Arctic Lab and with the assistance of the PASPC, has been developing many potential improvements to CARDS. To improve these algorithms and products, forecast model data and lightning data have now been integrated with the radar data.

Model-based data soundings can be interpolated in time and space to the storm cell site to assist in diagnosis. Total reflectivity volume and reflectivity volume colder than a threshold temperature are now used to identify a cell. Lightning data characteristics are then associated with each cell. The cell-tracking algorithm has been supplemented with knowledge of the change in cell volume, model winds aloft, and a mean observed motion of neighbouring cells. The hail algorithm has been adjusted to use a freezing level interpolated to the cell. Model wet-bulb temperatures can be overlaid on radar data to attempt to help detect the bright band melting zone. Using model data, the radar data can now be displayed on constant temperature (CoTPPI) surfaces in addition to constant altitude (CAPPI) surfaces. Model temperatures can now be overlaid on vertical cross-sections of radar data.

doppler-based improvements have been made to the product suite. Vertical cross-sections of radial velocity can now be generated. Observed storm-relative radial velocities are shown with each cell. The Velocity Azimuth Display has been augmented to allow winds to be displayed on a hodograph, as well as on a graph of wind barbs versus height. Wind shear and storm-relative helicity parameters are also calculated.

Finally, a number of further enhancements have been achieved. The Bounded Weak Echo Region (BWER) algorithm has been enhanced to improve detection and to reduce false alarms. The Rank Weight score for each cell has been modified to add the BWER volume, and to adjust the relative weighting of the algorithm's seven other parameters. The Storm Cell Identification Table (SCIT) has been improved to show detailed location and motion of the cell, BWER volume, BWER height, cell core volume, cell core volume less than -10C, as well as a number of lightning statistics

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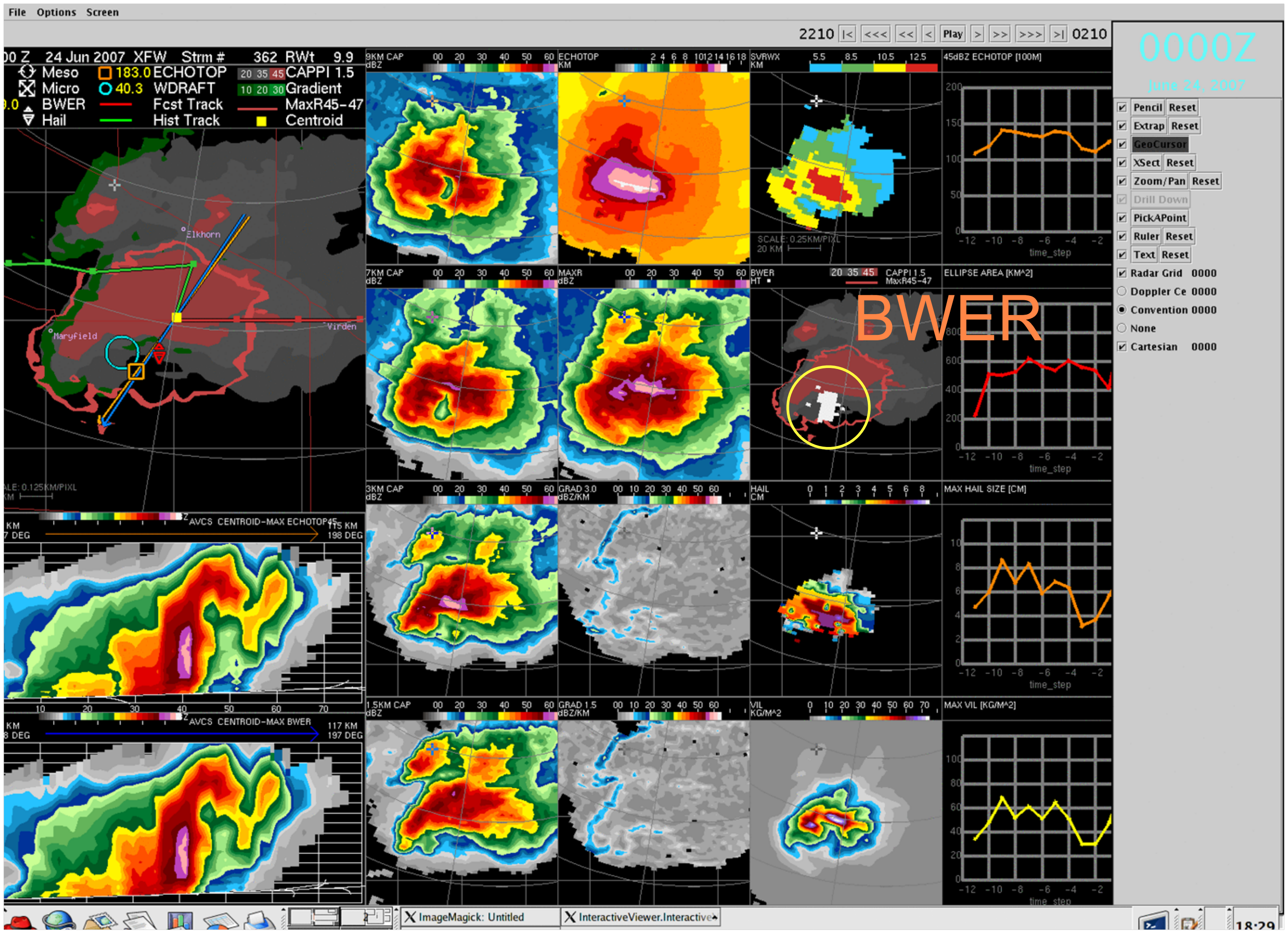


Figure 1. Cell view window: 1) composite view upper left, 2) 2 automated cross-sections (lower left), 3) next column to the right, CAPPI slices at 4 different AGL layers, 4) next column to the right (from top to bottom), echo tops, MaxR, two gradient CAPPIs, 5) next column to the right from top to bottom, SVRWX, BWER (indicated by white area), HAIL, VIL density, and 6) right column, trends in various parameters.

Screen

Table Time: 0000

sNumber	Distance	Dirn	Location	Radar	RankWeight	Meso_ave	Hail_cm	BWERvol_...	BWERhgt_...	WDraft_k...	VILDens	MaxZ	ETop45_...	CoreVolu...	ColderVol...	LtgCount	PosCGPct	MaxAmp	FlashDens	FlashTend	MeanVel_...
2	24km	W	Virden	XFW	9.9	0.0	7.9	189	10.4	145	5.3	63	13.9	4964	3410	91	36	90	0.11	-1.0	275/58
14	40km	W	Alonsa	XWL	6.8	N/A	5.3	1	2.9	89	3.2	62	11.1	2321	1130	37	0	-42	0.07	0.2	254/60
15	63km	NNE	Sprag...	XWL	5.9	N/A	4.7	0	0.0	73	3.4	61	10.9	871	677	47	8	-36	0.30	2.6	265/21
21	90km	ESE	Pinawa	XWL	5.1	N/A	3.9	0	0.0	60	2.6	58	8.5	539	458	4	0	-44	0.03	0.0	305/36
23	48km	ESE	Russell	XFW	3.8	5.1	1.6	0	0.0	47	1.5	56	7.7	231	78	48	57	102	0.34	-2.0	263/40
18	36km	SSE	Russell	XFW	3.8	3.7	1.0	0	0.0	50	4.2	60	7.2	704	110	24	24	60	0.07	-1.2	263/40
13	42km	NNW	Daup...	XFW	3.1	0.0	0.9	0	0.0	62	2.6	57	6.6	372	89	5	0	-38	0.04	-0.6	235/85
20	25km	WNW	Daup...	XWL	1.7	N/A	0.0	0	0.0	31	0.9	48	6.7	80	27	1	0	-12	0.04	-0.2	267/62

No row is selected.

Figure 2. New SCIT.

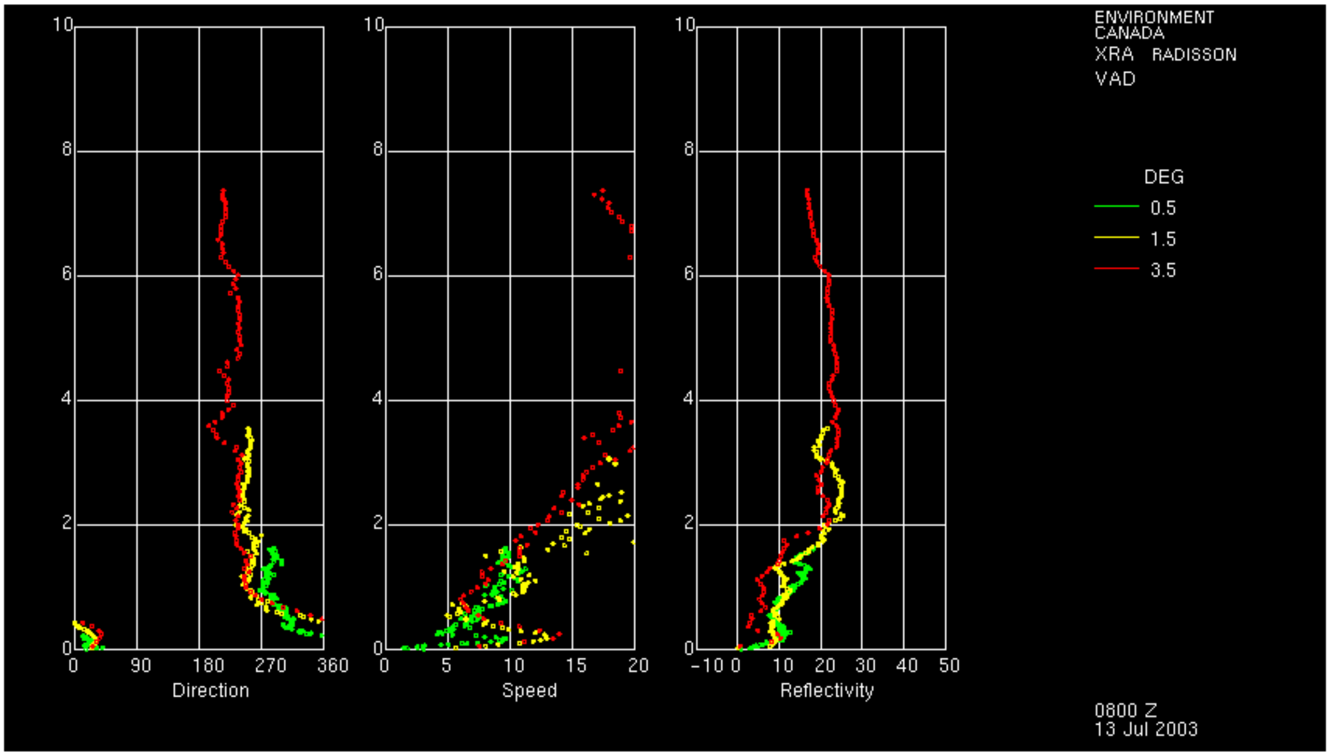


Figure 3. Old VAD.

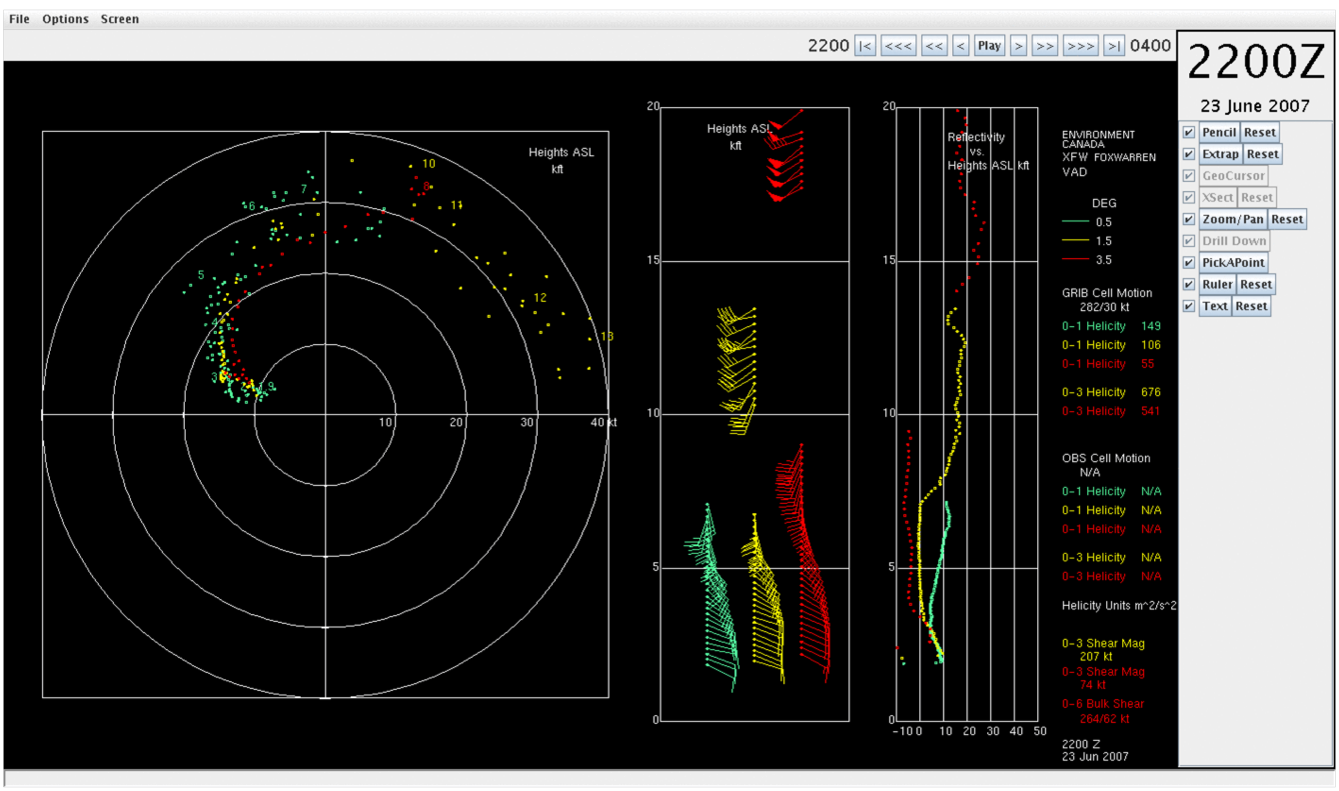


Figure 4. New VAD. Left view is the hodograph, Left centre view is the wind profile, right centre is the old VAD view, and right are calculates storm motion and helicity.

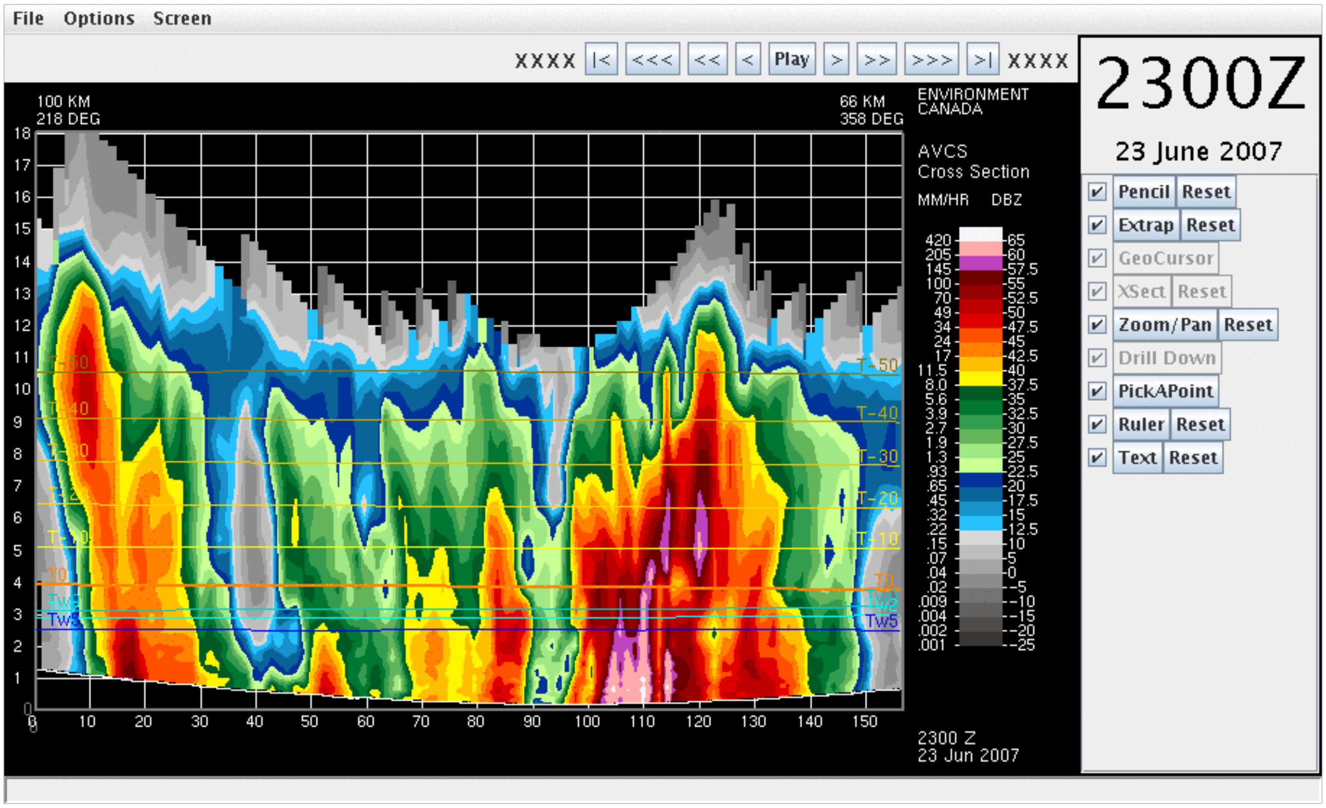
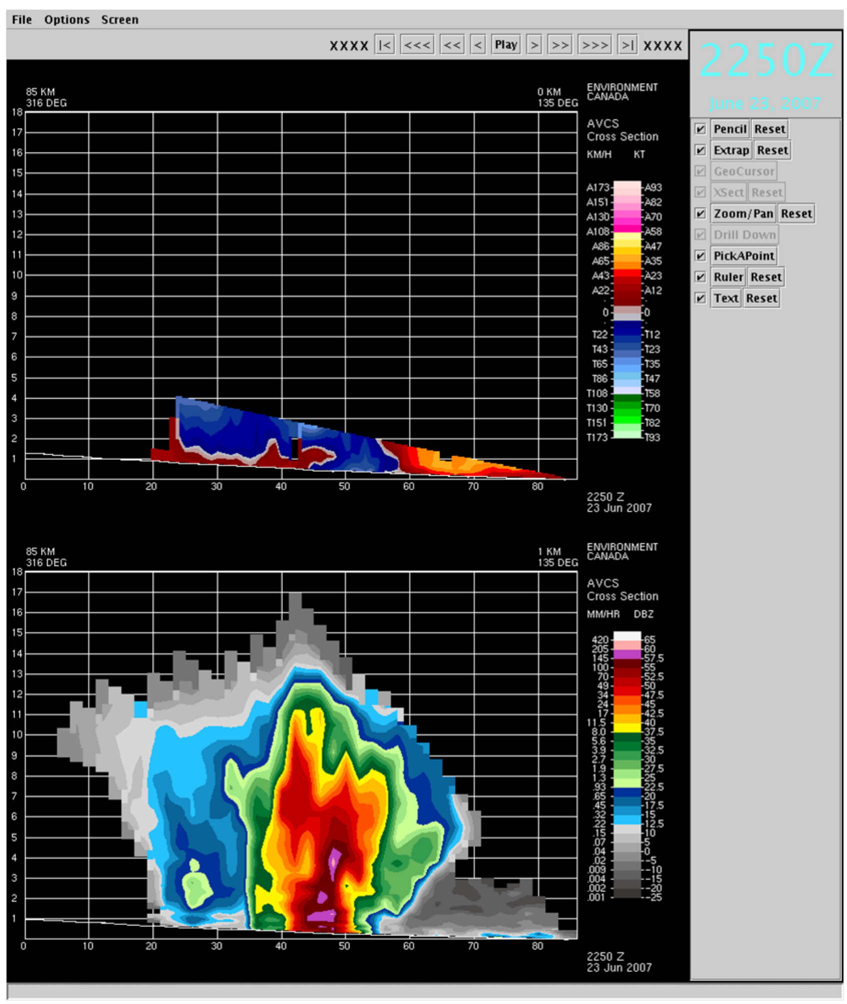


Figure 5. Cross-section with Temperature (T) contour lines and Wet Bulb Temperature (Tw) contour lines.

Figure 6. Cross-section with radial velocity above and the associated reflectivity below.



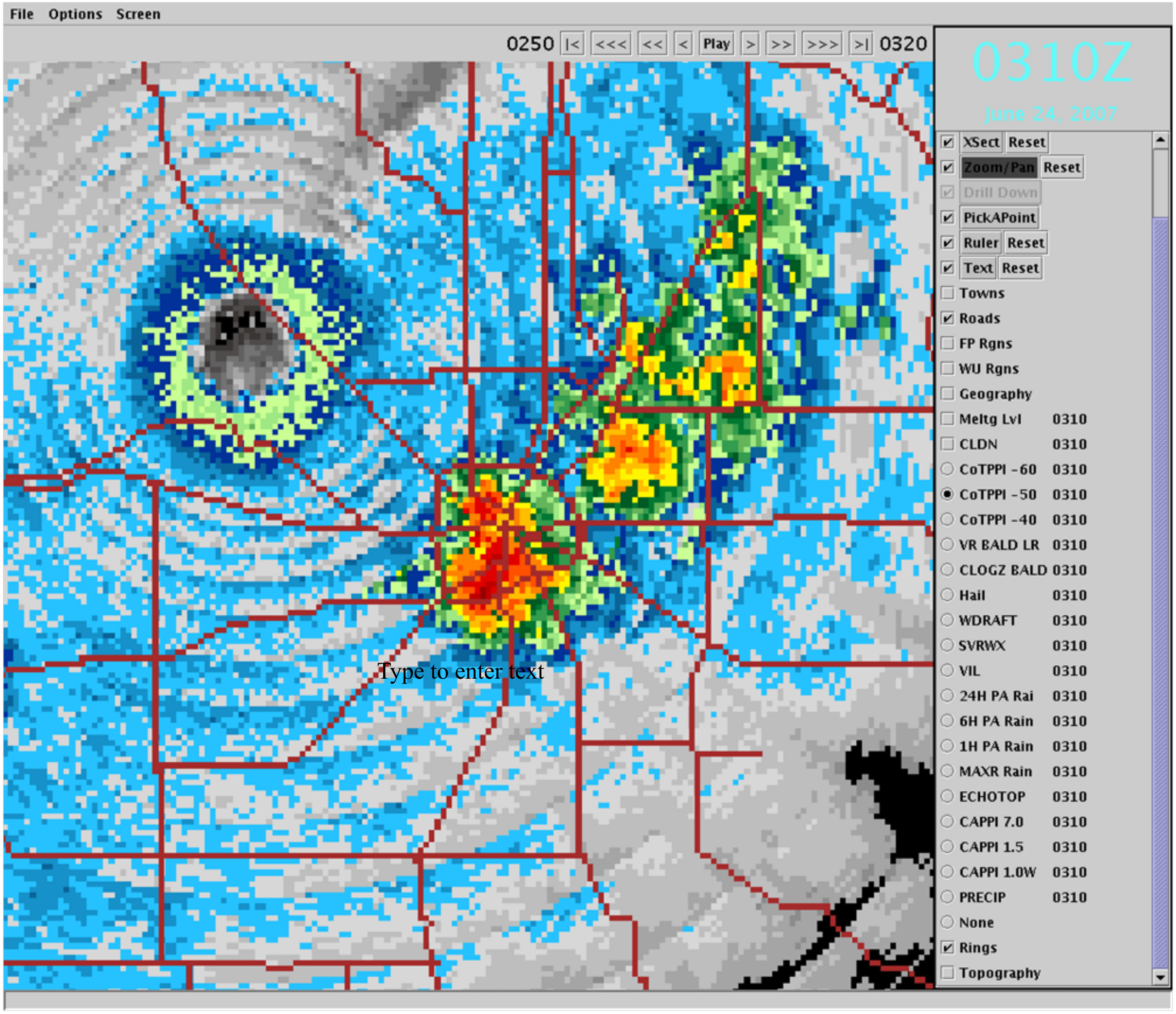


Figure 7. CoTPPI displaying reflectivity having a model-based temperature of -50C.